Hazards of Communication Satellites

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TO MANY people, communication satellites seem as new in concept as they are in physical fact, although the idea of communication satellites is over 15 years old.

The idea of earth satellites for communication is credited to Arthur C. Clarke, who in 1945, said:

"Although it is possible, by a suitable choice of frequencies and routes, to provide telephony circuits between any two points or regions of the Earth for a large part of the time, long distance communication is greatly hampered by the peculiarities of the ionosphere, and there are even occasions when it may be impossible.

"Unsatisfactory though the telephony and telegraph position is, that of television is far worse, since ionospheric transmission cannot be employed at all.

"It will be possible in a few more years to build radio controlled rockets which can be steered into such orbits beyond the limits of the atmosphere and left to broadcast scientific information back to the Earth. A little later, manned rockets will be able to make similar flights with sufficient excess power to break the orbit and return to Earth.

"It will be observed that one orbit, with a radius of 42,000 kilometers, has a period of exactly 24 hours. A body in such an orbit, if its plane coincided with that of the Earth's equator, would revolve with the Earth and would thus be stationary above the same spot on the planet. It would remain fixed in the sky of a whole hemisphere and unlike all other heavenly bodies would neither rise nor set. A body in a smaller orbit would revolve more quickly than the Earth and so would rise in the west, as indeed happens with the inner moon of Mars.

"Using material ferried up by rockets, it would be possible to construct a 'space station' in such an orbit. The station could be provided with living quarters, laboratories and everything needed for the comfort of its crew, who would be relieved and provisioned by a regular rocket service.

"A single station could only provide coverage to half the globe, and for a world service three would be required, though more could be readily utilized.

"The power required for the broadcast service would thus be about 1.2 kilowatts.

"When it is remembered that these figures relate to the broadcast service, the efficiency of the system will be realized. The point to point beam transmissions might need powers of only 10 watts or so.

"It seems fairly certain that frequencies from, say, 50 to 100,000 megacycles per second could be used without undue absorption in the atmosphere or the ionosphere."

Naturally, there are ideas that can be questioned in Clarke's early, pioneering paper. Perhaps his estimates of the power required for broadcasting are somewhat low. In comparison with relaying messages across oceans, broadcasting satellites seem rather difficult and not too attractive. Clarke thought in terms of 22,300 mile high "stationary" satellites; today lower orbits seem to have some advantages. Clarke thought in terms of manned space stations; today these seem very remote, while experimental communication satellites have actually been realized. Clarke thought that frequencies up to 100,000 megacycles per second could be used; we now know that not only oxygen and water vapor absorption, but rain attenuation as well, make such frequencies unattractive.

The Author's View in 1955

In 1955 I discussed possibilities of satellite communication in a paper written before I had read Clarke's. Some extracts follow:

"Two different sorts of satellite radio repeaters suggest themselves. One consists of enough spheres in relatively near orbits so that one of them is always in sight at the transmitting and receiving locations. This sphere isotropically scatters the transmitted signal, so one has merely to point the transmitter and receiver antennas at it to complete the path. Another system uses a plane mirror or an active repeater with a 24-hour orbital period, located directly above the equator at a radius of around 26,000 miles or an altitude of about 22,000 miles.

"For instance, only transoceanic communication has been mentioned, and for a reason. There are at present transcontinental television circuits. The announced cost of the American Telephone and Telegraph Company's transcontinental TD2 microwave system was 40 million dollars. This is only 5 million dollars more than the 35 million for the 36-channel transatlantic cable, and yet the TD2 system provides a number of television channels in both directions, as well as many telephone channels. Perhaps even more important in an overland system, it provides facilities for

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dropping and adding channels along the route. Without such flexibility, and overland system would be almost useless.

"The great advantages of the passive repeaters over active repeaters are potential channel capacity and flexibility. Once in place, passive repeaters could be used to provide an almost unlimited number of two-way channels between various points at various wavelengths. They would also allow for modifications and improvements in the ground equipment without changes in the repeater.

"Spheres, which reflect isotropically, are the most flexible of passive repeaters, because they allow transmission between any two points in sight of them. Moreover, with spheres there is no problem of the angular orientation of the repeaters.

"The disadvantage of passive repeaters is the great path loss, so that even assuming antennas of a difficult if not prohibitive diameter and accuracy, the power required is large, although probably attainable.

"The attractive feature of an active repeater is the small power required and the small antennas needed at the repeater, as well as the small power required at the ground.

"In conclusion, it can be said that, disregarding the feasibility of constructing and placing satellites, it seems that it might be possible to achieve broad-band transoceanic communication using satellite repeaters with any one of three general types of repeater: spheres at low altitudes, or a plane reflector or an active repeater in a 24-hour orbit (at an altitude of around 22,000 miles)."

The proposal is for relaying across oceans rather than either a universal transmission service or broadcasting. Further, unlike Clarke's, the satellites are to carry no men, and perhaps not even radio equipment. In writing the paper, I did not appreciate how small an orienting effect the gravitational gradient has, in comparison with light pressure, for instance.

Recent Proposals Are More Moderate

In September 1960 W. E. Morrow, Jr. proposed:

"This paper discusses the properties of a new type of long range radio communication technique which makes use of the scattering of microwave energy from a large number of scatterers distributed in orbit about the Earth. This technique has the advantage that only two orbiting belts of scatterers are required to achieve global long range communication coverage. There are additional advantages of very modest ground antenna tracking requirements, high reliability, and the ability to support a very large number of independent circuits."

Here a satellite communication system is reduced to the simplest possible form—a swarm of dipoles rotating as a belt around the Earth.

It is scarcely necessary to point out that the later proposals are less ambitious than those made earlier. This is not characteristic of all writings about satellite communication. Such conservatism reflects in part an increased appreciation of the uncertainties of space technology. It reflects in part the desire to achieve practical results quickly. The need for more transoceanic circuits is real and present.

In the first year of its service, the quality and magnitude of communication provided by the first transoceanic telephone cable of 1956 led to a 70 per cent increase in the number of transatlantic calls, and to longer calls as well. Last year overseas calls increased nearly 20 per cent. Cables have been laid to Hawaii, Alaska, Puerto Rico and France; an additional cable of increased capacity to Europe is planned, as well as one to Japan. Overseas telephone service is expanding so rapidly that it alone could justify a satellite communication system.

Some argue whether the large time difference between Europe and America might preclude transoceanic television. I don't believe that we will know until we actually have broad-band transoceanic circuits. Certainly, however, there will be ample uses for broad-band circuits for voice, data and picture transmission. Transoceanic TV will be tried and may succeed.

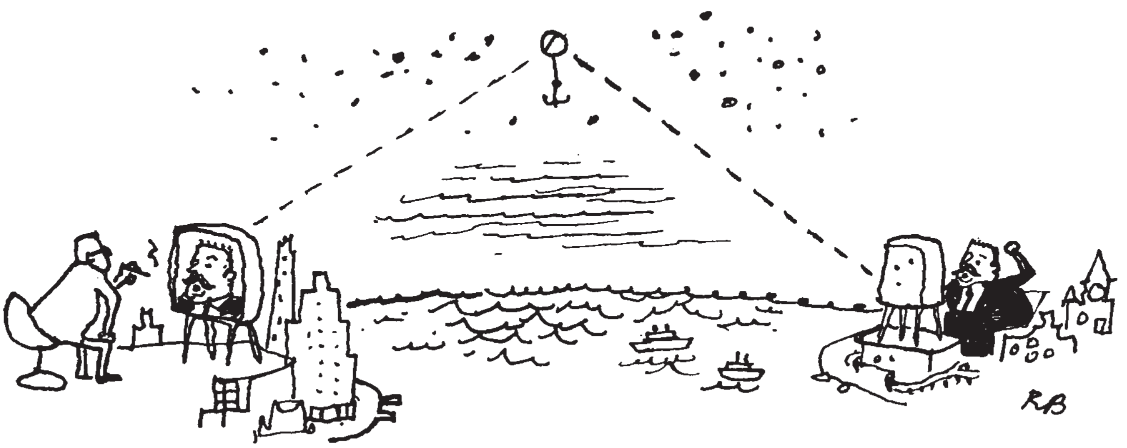
In 1945 and 1955 we had neither the urgent need for nor the ability to orbit communication satellites. Today Score, Echo, and Courier have been orbited. But, we know that half of the launchings in our space program fail. Further, the life of many payloads, including Score and Courier, has been far short of that necessary in a useful communication, and Echo is an experiment, not an attempt to provide practical, economical communication. Much research and development lie between us and the realization of even the simplest practical satellite communication systems.

Satellite communication is an outgrowth of two arts. On the one hand, it is made possible by a new, shaky and very expensive art of space flight. This essential art has been brought into being at government expense through our missile and space programs with other ends than satellite communication in view. A sensible satellite communication program must make use of existing vehicles. Even modifications of existing vehicles are technically hazardous as well as costly. The other art is a mature and manageable art of ground electronics and communications. The two arts are blended in the electronic payload.

Problems and Means

Electronics in space suffers from a number of hazards All equipment must withstand tens of g's of acceleration during launch. Ultimately, only radiation cooling is available; heat must be conducted to radiating surfaces. There can be no convection even in a pressurized container, for there is no gravity. In an alternate environment of sunlight and shadow, temperature variations are large.

Vacuum and gas at atmospheric pressure are good insulators, but pressures are encountered during ascent at which a discharge can be initiated at a comparatively low voltage. Once in orbit, pressurized containers may leak, and vapors from apparatus can produce appreciable gas densities. The seals on storage batteries sometimes leak.



Finally, radiation progressively reduces the efficiency of the solar cells on which space payloads depend for power. And, our knowledge concerning the integrated amount of radiation a satellite encounters may be uncertain by an order of magnitude.

Undoubtedly, long life can be achieved in space, but many problems must be tackled with a care and thoroughness which have not been characteristic of our mad scramble into space.

Beyond purely electronic hazards, some communication satellite proposals call for oriented satellites. It seems possible that very low satellites can be oriented passively by gravitational gradient, but how low is low, and when will this be demonstrated? Passive orientation by means of the Earth's magnetic field may work up to the height at which the Earth's magnetic field is stable, but not for 22,300 mile "stationary" satellites. The only means of orienting such satellites appear to be flywheels plus gas jets or other impulse producing devices.

Such "active" orientation has been demonstrated for a few days, but not for the years called for by communication satellites. Much remains to be done. The operation of mechanisms in a vacuum is hazardous, and so are pressurized containers. If orientation is achieved or influenced by command, there is an added hazard that the system will be activated by a foreign transmitter. If elaborate codes are used to avoid this, there is a great hazard that malfunction will make the equipment unresponsive to legitimate commands. These are not idle worries; space payloads and command systems have been sadly fallible in practice.

The Case for Simplicity

It is clear that the hazards of satellite communication lie in the vehicle and its launching, and in the proper functioning of the payload. The expense of a satellite system will be largely the cost of launching and replacing satellites. Bugaboos about ground antennas and the tracking of nonstationary satellites have been raised, but I think that they are unwarranted. Echo was automatically tracked to within a tenth of a degree by means of orbital data. Because of its large area to mass ratio, Echo has had an unusually rapidly changing orbit, and undoubtedly with refined equipment a smaller satellite could be tracked considerably more accurately. But the bugaboos which have been raised about space payloads are with us every day.

Under these circumstances, a strong case can be made for using a very simple satellite, even though this calls for more complicated ground equipment.

Should we go so far as to use passive balloon satellites like Echo, or a belt of dipoles? This seems to call for ground transmitter powers of several tens of kilowatts for television bandwidths. Such large powers increase the hazard of long range interference with ground microwave systems. Dipoles form a multipath medium, and large bandwidths can be obtained only by tricky means.

Light, low power active satellites are an attractive alternative. A light satellite means that one can ultimately launch more satellites per vehicle. As power governs weight, a low power transmitter seems desirable. This has further advantages in that low power microwave tubes last much longer than high power tubes and low power satellite transmitters will not interfere with ground microwave systems, while high power transmitters might.

To Get the Most For the Least

To get the most results with the least satellite equipment calls for a sensitive receiver. In the Echo experiment, a receiving system noise temperature of around 24 degrees Kelvin is attained by using a ruby maser and horn reflector antenna, and this could be bettered. Below 1000 megacycles per second, cosmic noise vitiates the advantages of such a receiver. Above 10,000 megacycles per second the absorption of atmospheric oxygen and water vapor lead to appreciable thermal noise from the atmosphere, and thermal noise during rain would cause increasing interruption of service with increasing frequency.

Besides sensitive receivers, one can use broadband modulation schemes in reducing the power required aboard the satellite. Frequency modulation with an index of 10 gives a 20 decibel gain (100 times), but calls

for a bandwidth of about 100 megacycles per second to transmit a TV signal or 600 telephone channels. Although broad band modulation reduces the number of separate frequency channels in a given block of frequencies, it also reduces interference between systems operating on the same frequency and would make it possible to use the same frequency channel for simultaneous transmission to or reception from satellites in many parts of the sky.

By using a sensitive maser receiver together with an antenna 60 feet in diameter, and a broad band form of modulation, one could transmit a TV signal from a 3000 mile high omnidirectional satellite antenna to ground with about a watt of power. The same power would suffice for a 24-hour "stationary" satellite providing that the satellite made use of a directional antenna with a beamwidth just broad enough to cover the Earth.

One satellite system which has been proposed uses low altitude satellites (2000–6000 miles high), with passive or no orientation, in large enough numbers (some tens) so that by chance one satellite is almost always available for each path. Such a system is subject to predictable, infrequent outages. While many satellites are required, a given satellite could successively serve different paths in different parts of the world. The loss of a few satellites would degrade the performance of such a system inappreciably. Presumably, such satellites would be launched from time to time in batches of perhaps ten.

Another satellite system, which the Army's Advent program envisages, makes use of a few 24-hour "stationary" satellites, complete with orientation, station-keeping and command control. Proponents of such a system sometimes talk in terms of three such satellites. This would be hazardous to the point of being ridiculous, for the loss of a single satellite would disrupt some paths completely. Such a satellite system has a disadvantage for common carrier telephony. The round trip delay of about half a second is noticeable and to many quick-speaking users very annoying—a nuisance which users of the transoceanic cables are spared.

Forecast for Satellite Communication

Very sketchily, then, such are the history and the technical prospects of satellite communication. What other problems does it face? What of its future?

It is clear after even the most superficial examination that satellite communication must first be used to link the extensive land communications which already exist. To speak of any initial application in serving underdeveloped areas would be like a proposal (back during the war) that the atom bomb be built in some African or South American country because it would be good for that country's economy. Whatever benefits developing nations will gain from satellite communication must spread out to them from more highly developed economies and technologies—or must come from the freeing of high frequencies which underdeveloped countries could then use.

Let us turn to the problem of linking, say, Western Europe with America by means of a satellite communication system. One problem is of course that of frequencies.

The frequencies needed are the sort of microwave frequencies which are used for a wide variety of military and civilian purposes. Microwave systems are proliferating like rabbits in Australia, and there aren't enough frequencies for all proposed uses. Efficient and economical worldwide satellite communication will ultimately require the allocation of thousands of megacycles of microwave frequencies on a *worldwide basis*. The use of these frequencies for other purposes may be impossible within a radius of a hundred miles, or perhaps more, from any satellite ground terminal. Thus, effective transoceanic communication by means of satellites necessarily requires that the use of microwave frequencies for communication over land must be limited and controlled. This is a difficult problem now faced by national and international organizations, among them the International Telecommunications Union, now a part of the United Nations.

"Ownership" of Satellites

Another and nontechnological problem is that of ownership and operation of the satellites (if one can own a satellite) and of the ground equipment used in satellite communication. Traditionally, transoceanic communications have been carried out cooperatively on a nonpolitical basis by the various organizations which provide telephone and telegraph service. In most countries these are departments of the government, usually the post office, as in Great Britain, France and Germany. In some countries, as in Canada, the organization is a government-owned corporation. In our own country, regulated private corporations provide telephone and telegraph service.

In the case of transoceanic radio, in each country the organization which provides telephone or telegraph service owns and operates the shortwave transmitters and receivers in its territory, whether this be the USSR, Great Britain or the United States. In the case of telephone cables, the cable is paid for and owned jointly by the telephone organizations of the countries which it links. This seemingly complicated ownership of international communication facilities has a long tradition of successful operation among countries of the most widely varying and antagonistic politics. In some countries it is a matter of law as well as of tradition. It has been little affected even by the cold war.

There is no financial or technological obstacle to following the same pattern in satellite communication. The initial cost of a satellite communication system will be comparable to that of a large cable system. The Ameri-

can Telephone and Telegraph Company has announced that it is prepared to bear the costs of communication satellite research, including launchings, and its share of the cost of an international communication system. The Bell Laboratories is vigorously pursuing a program of satellite communication research and development. Technologically, satellites are merely a new and powerful way of providing more and better international electrical communication.

The Propaganda Problem

There are, however, many people who regard the science and technology of space, not as one aspect of the world's long course of scientific and technological progress, but primarily as a unique battleground of the cold war, in which national prestige is to be lost or won. Such people are apt to ask, can't we use satellite communication against unfriendly countries, or at least to stay ahead of the Soviets in some sense? Can't our government give satellite communication to other countries as a very special gift, and thus curry favor with them?

Such an attitude is dangerous. In divorcing space science and technology from the centuries of science and technology of which it is a part, we not only misinterpret its nature; we also abandon successful ways of dealing with real national and international problems and raise a host of new problems which are not truly relevant to the exploitation of space.

Satellite communication has already added to our prestige. But, satellite communication is no mere trick or weapon of propaganda. It promises substantial benefits to the citizens of all nations. It promises prompt, adequate and economical transoceanic telephony. Beyond this, it promises the immediacy of television.

Achieving these things is not going to be easy. Overambitious and technically marginal plans could block progress. Extraneous issues are perhaps even more hazardous. It will be hard enough to work out a scheme for international satellite communication without our insisting that the scheme must aid backward nations, put the U.N. in the communication business, or serve as a political issue. Happily, the National Aeronoutics and Space Administration has so far followed an encouraging and helpful course. We can only hope that political monsters will not be evoked along what is, from a purely technical point of view, a hazardous and costly course.